CLAIMS

1. A continuous method for reducing one or more of microorganisms or enzymes in a liquid product, said method comprising the steps of:

a) forming a pressurized mixture by

i) combining a pressurized flow of said liquid product with a flow of pressurized liquefied carbon dioxide to create a pressurized mixture in a flow state, said carbon dioxide at a pressure sufficient to maintain it in a liquid state and at a temperature which does not freeze said liquid product; or

ii) forming a mixture of said liquid product with liquid or gaseous carbon dioxide, wherein said carbon dioxide if in the liquid state is at a pressure sufficient to maintain it in a liquid state and at a temperature which does not freeze said liquid product, and then pressurizing said mixture;

b) flowing said pressurized mixture through a reaction zone for a sufficient time to reduce at least one of said microorganisms and said enzymes in said liquid mixture;

c) feeding said pressurized mixture from said reaction zone through one or more expansion stages wherein the pressure of said mixture flow is decreased to vaporize the carbon dioxide in said mixture; and

d) applying heat in at least one of said expansion stages to said mixture if necessary, to the extent necessary, to prevent cooling of said carbon dioxide from causing freezing of said liquid product.

2. The continuous method as recited in claim 1, wherein step a) comprises combining a pressurized flow of said liquid product with a flow of pressurized liquefied carbon dioxide to create a pressurized mixture in a flow state, said carbon dioxide at a pressure sufficient to maintain it in a liquid state and at a temperature which does not freeze said liquid product.

3. The continuous method as recited in claim 2, wherein in step d) heat is applied to said mixture in at least one of said expansion stages.

4. The continuous method as recited in claim 3, wherein step d) maintains the temperature of said mixture within a range between the freezing temperature of said liquid product and about 60°C.

5. The continuous method as recited in claim 2, wherein step c) feeds said mixture flow through two or more expansion stages to vaporize said liquefied carbon dioxide.

6. The continuous method as recited in claim 2, wherein step a) feeds said pressurized flow of said mixture in said reaction zone at a pressure within a range of about 300 psia to about 20,000 psia.

7. The continuous method as recited in claim 2, wherein step b) maintains said pressurized flow of said mixture in said reaction zone for a duration of from

about 5 seconds to about 30 minutes.

8. A continuous method as recited in claim 1, wherein step a) comprises forming a mixture of said liquid product with liquid or gaseous carbon dioxide, wherein said carbon dioxide if in the liquid state is at a pressure sufficient to maintain it in a liquid state and at a temperature which does not freeze said liquid product, and then pressurizing said mixture.

9. The continuous method as recited in claim 8, wherein in step d) heat is applied to said mixture in at least one of said expansion stages.

10. The continuous method as recited in claim 9, wherein step d) maintains the temperature of said mixture within a range between the freezing temperature of said liquid product and about 60°C.

11. The continuous method as recited in claim 8, wherein step c) feeds said mixture flow through two or more expansion stages to vaporize said liquefied carbon dioxide.

12. The continuous method as recited in claim 8, wherein step a) feeds said pressurized flow of said mixture in said reaction zone at a pressure within a range of about 300 psia to about 20,000 psia.

13. The continuous method as recited in claim 8, wherein step b) maintains said pressurized flow of said

mixture in said reaction zone for a duration of from about 5 seconds to about 30 minutes.

14. A continuous method for reducing microorganisms and inactivating one or more enzymes in liquid juice product, said method comprising the steps of:

a) forming a pressurized mixture by

i) combining a pressurized flow of said liquid juice product with a flow of pressurized liquefied carbon dioxide to create a pressurized mixture in a flow state, said carbon dioxide at a pressure sufficient to maintain it in a liquid state and at a temperature which does not freeze said liquid juice product; or

ii) forming a mixture of said liquid juice product with liquid or gaseous carbon dioxide, wherein said carbon dioxide if in the liquid state is at a pressure sufficient to maintain it in a liquid state and at a temperature which does not freeze said liquid juice product, and then pressurizing said mixture;

b) flowing said pressurized mixture through a reaction zone for about 1.0 to about 15 minutes to reduce said microorganisms present therein and inactivate said one or more enzymes;

c) feeding said pressurized mixture from said reaction zone through one or more expansion stages wherein the pressure of said mixture flow is decreased; and

d) applying heat in at least one of said expansion stages to said mixture flow if necessary, to the extent necessary, to prevent cooling of said carbon

dioxide from causing freezing of said liquid juice product.

15. The continuous method as recited in claim 14, wherein the juice is a vegetable or fruit juice and wherein the contact time in step b) is about 1.5 to about 13 minutes.

16. The continuous method as recited in claim 14, wherein step d) maintains the temperature of said mixture within a range between the freezing temperature of said liquid juice product and about 30°C.

17. The continuous method as recited in claim 14, wherein said juice is orange juice, said contact time is about 3.0 minutes, and wherein step d) maintains the temperature of said mixture at about 30°C.

18. The continuous method as recited in claim 17, wherein step a) feeds said pressurized flow of said mixture in said reaction zone at a pressure of about 5,000 psia.

19. Apparatus for performing a continuous method of reducing microorganisms in a liquid product, said apparatus comprising:

a) means for providing a pressurized mixture, comprising either

i) pump means for providing a pressurized flow of said liquid product and liquefied carbon dioxide and for creating a pressurized mixture thereof

in a flow state, said pump means pressurizing said carbon dioxide to a pressure that is sufficient to maintain it in a liquid state but at a temperature that does not freeze said liquid product; or

(ii) means for mixing liquid carbon dioxide with said liquid product, or means for mixing gaseous carbon dioxide with said liquid product, and means for pressurizing the resultant mixture;

b) reaction zone means for receiving said pressurized mixture in a continuous flow state, and for enabling a residence time therein of said pressurized mixture that is sufficient to allow said carbon dioxide to reduce microorganisms in said liquid product;

c) one or more expansion devices for receiving said pressurized mixture flow from said reaction zone, each expansion device configured to enable a reduction of the pressure of said mixture flow, so as to allow said mixture flow to exit said one or more expansion devices at a desired exit pressure; and

d) heat exchange means for applying heat to said liquid mixture in at least one of said expansion devices if necessary, to the extent necessary, to prevent cooling of said carbon dioxide therein and causing freezing of said liquid product.

20. The apparatus as recited in claim 19, wherein said heat exchange means maintains a temperature of said mixture within a range between the freezing temperature of said liquid product and 60°C.

21. The apparatus as recited in claim 19, wherein said plural expansion devices consist of two or more expansion stages and said exit pressure is ambient.

22. The apparatus as recited in claim 19, wherein said pump means feeds said pressurized flow of said mixture into said reaction zone means at a pressure within a range of about 300 psia to about 20,000 psia.

23. The apparatus as recited in claim 19, wherein said reaction zone means provides a residence time, for said pressurized flow of said mixture, of a duration of from about 5 seconds to about 30 minutes.

24. The apparatus as recited in claim 19, wherein said liquid product is orange juice and said heat exchange means maintains a temperature of said mixture within a range between the freezing temperature of said orange juice and 30°C.

25. The apparatus as recited in claim 24, wherein said plural expansion devices consist of two or more expansion stages and said exit pressure is between about 250 psia to about 850 psia.

26. The apparatus as recited in claim 25, wherein said pump means feeds said pressurized flow of said mixture into said reaction zone means at a pressure of about 5,000 psia.

27. The apparatus as recited in claim 24, wherein

said reaction zone means provides a residence time, for said pressurized flow of said mixture, of a duration of about 3 minutes.

28. A continuous method for reducing microorganisms in a liquid product, said method comprising the steps of:

a) combining a pressurized flow of said liquid product with a flow of pressurized liquefied carbon dioxide to create a pressurized mixture in a flow state, said carbon dioxide at a pressure sufficient to maintain it in a liquid state and at a temperature which does not freeze said liquid product;

b) flowing said pressurized mixture through a reaction zone for a sufficient time to reduce microorganisms in said liquid product;

c) feeding said pressurized mixture from said reaction zone through plural expansion stages wherein the pressure of said mixture flow is decreased to vaporize the liquefied carbon dioxide in said mixture flow; and

d) applying heat in at least some of said expansion stages to said mixture flow to prevent a cooling of said carbon dioxide from causing a freezing of said liquid product.

29. The continuous method as recited in claim 28, wherein step d) maintains a temperature of said mixture within a range between a freezing temperature of said liquid product and about 60°C.

30. The continuous method as recited in claim 28, wherein step c) feeds said mixture flow through two or more expansion stages to vaporize said liquefied carbon dioxide.

31. The continuous method as recited in claim 28, wherein step a) feeds said pressurized flow of said mixture in said reaction zone at a pressure within a range of about 300 psia to about 20,000 psia.

32. The continuous method as recited in claim 28, wherein step b) maintains said pressurized flow of said mixture in said reaction zone for a duration of from about 5 seconds to about 30 minutes.

33. The continuous method as recited in claim 28, wherein said liquid product is a food product and said method inactivates one or more enzymes.

34. A continuous method for reducing microorganisms and inactivating one or more enzymes in liquid juice product, said method comprising the steps of:

a) combining a pressurized flow of said liquid juice product with a flow of pressurized liquefied carbon dioxide to create a pressurized mixture in a flow state, said carbon dioxide at a pressure sufficient to maintain it in a liquid state and at a temperature which does not freeze said liquid juice product;

b) flowing said pressurized mixture through a reaction zone for about 1.0 to about 15 minutes to

reduce said microorganisms present therein and inactivate said one or more enzymes;

c) feeding said pressurized mixture from said reaction zone through two or more expansion stages wherein the pressure of said mixture flow is decreased to about 2,000 psia; and

d) applying heat in at least some of said expansion stages to said mixture flow to prevent a cooling of said carbon dioxide from causing a freezing of said liquid juice product.

35. The continuous method as recited in claim 34, wherein the juice is a vegetable or fruit juice and wherein the contact time in step b) is about 1.5 to about 13 minutes.

36. The continuous method as recited in claim 34, wherein step d) maintains a temperature of said mixture within a range between a freezing temperature of said liquid juice product and about 30°C.

37. The continuous method as recited in claim 35, wherein said juice is orange juice, said contact time is about 3.0 minutes, and wherein step d) maintains a temperature of said mixture at about 30°C.

38. The continuous method as recited in claim 37, wherein step a) feeds said pressurized flow of said mixture in said reaction zone at a pressure of about 5,000 psia.

39. Apparatus for performing a continuous method of reducing microorganisms in a liquid product, said method comprising the steps of:

a) pump means for providing a pressurized flow of said liquid product and liquefied carbon dioxide and for creating a pressurized mixture thereof in a flow state, said pump means pressurizing said carbon dioxide to a pressure that is sufficient to maintain it in a liquid state but at a temperature that does not freeze said liquid product;

b) reaction zone means for receiving said pressurized mixture in a continuous flow state, and for enabling a residence time therein of said pressurized mixture that is sufficient to allow said carbon dioxide to reduce microorganisms in said liquid product;

c) plural expansion stages for receiving said pressurized mixture flow from said reaction zone, each expansion stage configured to enable a reduction of the pressure of said mixture flow, so as to allow said mixture flow to exit said plural expansion stages at a desired exit pressure; and

d) heat exchange means for applying heat to said liquid mixture in at least some of said expansion stages to prevent a cooling of said carbon dioxide therein and causing a freezing of said liquid product.

40. The apparatus as recited in claim 39, wherein said heat exchange means maintains a temperature of said mixture within a range between a freezing temperature of said liquid product and 60°C.

41. The apparatus as recited in claim 39, wherein said plural expansion stages consist of two or more expansion stages and said exit pressure is ambient.

42. The apparatus as recited in claim 39, wherein said pump means feeds said pressurized flow of said mixture into said reaction zone means at a pressure within a range of about 300 psia to about 20,000 psia.

43. The apparatus as recited in claim 39, wherein said reaction zone means provides a residence time, for said pressurized flow of said mixture, of a duration of from about 5 seconds to about 30 minutes.

44. The apparatus as recited in claim 39, wherein said liquid product is orange juice and said heat exchange means maintains a temperature of said mixture within a range between a freezing temperature of said orange juice and 30°C.

45. The apparatus as recited in claim 44, wherein said plural expansion stages consist of two or more expansion stages and said exit pressure is between about 350 psia to about 850 psia.

46. The apparatus as recited in claim 45, wherein said pump means feeds said pressurized flow of said mixture into said reaction zone means at a pressure of about 5,000 psia.

47. The apparatus as recited in claim 44, wherein

said reaction zone means provides a residence time, for said pressurized flow of said mixture, of a duration of about 3 minutes.